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ABSTRACT

In setting the speed limit, the government should consider only externalities, e.g., the tendency of one driver's speed to endanger other drivers. In this paper, we discuss the methodology for estimating the optimal speed limit, based on externalities. We carry out a numerical illustration to demonstrate how the methodology leads to (1) a numerical estimate of the optimum speed limit, (2) an estimate of the dollar loss from a suboptimum speed limit, (3) an estimate of cost per life saved, and (4) the suggestion that federal traffic data collection efforts and traffic studies be redirected toward discovering two crucial parameters: the speed drivers would go if left alone and the ratio of the external to internal marginal cost of highway speed.

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INTRODUCTION

The optimum speed (for a driver) and the optimum speed limit (imposed by a government) are two distinct concepts. The driver himself can determine his private optimum by balancing the danger (to himself) of a greater speed against the extra travel time.

But the private optimum and the social optimum are not the same. As a driver increases his own speed, he increases not only his own chance of an accident but that of other motorists, as well. Externalities of this type provide the sole rationale for government regulation of speed. The optimum speed limit is the private optimum adjusted to account for the difference between private and social cost.

Our central point is that it is only externalities that make it possible for a speed limit to generate net benefits. In the absence of externalities, a speed limit which forced drivers away from their own optimal speed would produce no return to society but would reduce the returns to individuals below what they could achieve by driving at their optima. It is failure to recognize this point that is the terminal weakness in virtually all benefit-cost analyses that have been done so far. The inappropriate criterion used in most benefit-cost studies could lead

to the conclusion that a limit should be imposed even in a hypothetical case in which there were no externalities.

In this paper, we describe the method for determining the optimal speed limit and give a simplified numerical example. The example illustrates what can be obtained from the formula for the optimum: (1) a numerical estimate of the optimum speed limit, (2) a numerical estimate (in dollars) of the loss from a suboptimal speed limit; (3) a numerical estimate of the cost, per life saved, of a speed limit below the optimum, which can be compared with the cost of saving lives in other ways; (4) an understanding of the types of information needed to improve estimates of the optimum; and (5) an understanding of what information currently collected (at great cost) is not needed.

Related Work

The present study is grounded on a number of valuable economic contributions in the literature. A number of studies have evaluated the 55-mph speed limit in the United States (see, for example, [5, 6, 11-14]). None of these, however, was directed toward deriving an optimal speed limit, nor did they acknowledge the central role of externalities. A study of English Motorways [8] estimated the optimum speed limit, but their method does not take proper account of

externalities. Several papers by Blomquist and Peltzman [2], [3], [4] recognize the crucial importance of externalities in public policy having to do with auto safety but do not make the application to the optimum speed limit. Clotfelter and Hahn [6] provide a good discussion of the role of externalities in the optimum speed limit, but they do not calculate the optimum nor do they recognize that the central role of externalities completely changes the information needed to calculate an optimum. In particular, it will be shown that in order to solve for the social optimum, it is not always necessary to estimate the value of a life, a major step forward given the range of estimates and the philosophical difficulties involved. The social optimum is derived as a rather straightforward adjustment to the personal optimum, a quantity, which under certain circumstances, can be observed directly.

THEORY

Consider a simple case in which a driver's utility (U) is a function of three variables: a consumption good (X), the probability of being killed in an accident (ρ), and travel time (T).¹ The

¹We are assuming that drivers are homogeneous and would choose to go the same speed. We realize that this ignores the well documented importance of variation in speed across drivers. Our purpose here, however, is to illustrate a principle. Once this is accepted more complex cases can be handled. This would include, for example, the probability and costs associated with nonfatal injuries.

dependence of U on T is meant to illustrate the fact that time is valuable, since other uses of time, including leisure or income production, decrease when one travels in an automobile.

The driver chooses X and S (speed) to maximize utility subject to his income constraint, $P_X X + P_G G = Y$, where

P_X = price of the consumption good

P_G = price of gasoline

G = quantity of gasoline

Y = income

The Lagrangian is

$$L = U(T, \rho, X) + \lambda(Y - P_X X - P_G G)$$

Utility is maximized with respect to speed when

$$U_1 \frac{\partial T}{\partial S} + U_2 \frac{\partial \rho}{\partial S} - \lambda P_G \frac{\partial G}{\partial S} = 0,$$

where U_1 and U_2 are partial derivatives of U w.r.t. the first two arguments, T and ρ .

We will approximate U_1 and U_2 by constants. Relating U_1 and U_2 to the values of life and time eases the interpretation:

$$U_1 = -V_T \lambda$$

$$U_2 = -V_L \lambda$$

where V_T is the value of time (dollars (1975) per hour)

V is the value of a life (dollars (1975) per

L person) as revealed by responses to the probability of being killed.¹

λ is the marginal utility of income.

$\partial T/\partial S$, $\partial \rho/\partial S$, and $\partial G/\partial S$ depend on the length of the trip, D (in miles). Since $T = D/S$,

$$\frac{\partial T}{\partial S} = \frac{-D}{S^2}$$

which expresses the dependence on D . Define $\alpha(S)$ as the probability of being killed per mile, and assume²

$$\frac{\partial \alpha}{\partial S} = \frac{\partial \rho}{\partial S} \frac{1}{D}$$

Finally, let $G = gD$, where g is the amount of gas used per mile so that

$$\frac{\partial G}{\partial S} = D \frac{\partial g}{\partial S}.$$

¹ More precisely, V_L is defined as $-\frac{\partial U}{\partial \rho} / \frac{\partial U}{\partial Y}$. In other

words, V_L is the amount of income necessary to compensate a driver for a very small change in the chance of being killed, divided by the amount the chance is increased.

² That D and ρ are roughly proportional may be derived as follows: the probability of having an accident in D miles is $1-(1-\alpha(s))^D$, or 1 minus the probability of not having an accident for D miles. We want to show that $1-(1-\alpha)^D = \alpha D$ or equivalently $(1-\alpha)^D = 1-\alpha D$. This is simply an approximation to the binomial theorem for α small.

The Private Optimum

To derive the private optimum, we consider a hypothetical case in which there are no externalities--all fatalities are one-car accidents. Thus, the driver need only worry about his own personal costs. The individual therefore equates the benefit from going faster, given by $\lambda V_T D/S^2$, with the private marginal cost, given by $\lambda V_L D \frac{\partial \alpha}{\partial S} + \lambda P_G D \frac{\partial g}{\partial S}$. The first term represents the costs of the increased chance of getting killed, the second the increased costs of gas consumption. Figure 1 presents the graphic representation leading to optimal speed, S_p .

The equilibrium speed for an individual (S_p) is given by

$$V_T/S_P^2 = V_L \frac{\partial \alpha}{\partial S} + P_G \frac{\partial g}{\partial S}$$

which reduces to

$$S_P = V_T^{.5} \left[V_L \frac{\partial \alpha}{\partial S} + P_G \frac{\partial g}{\partial S} \right]^{-.5} \quad (1)$$

Equation (1) shows that for an individual, the optimal speed depends positively on his value of time and negatively on his valuation of his own life, his subjective probability of being killed at higher speeds, and on the extra amount spent on gasoline at higher speeds. Barring unusual circumstances, such as

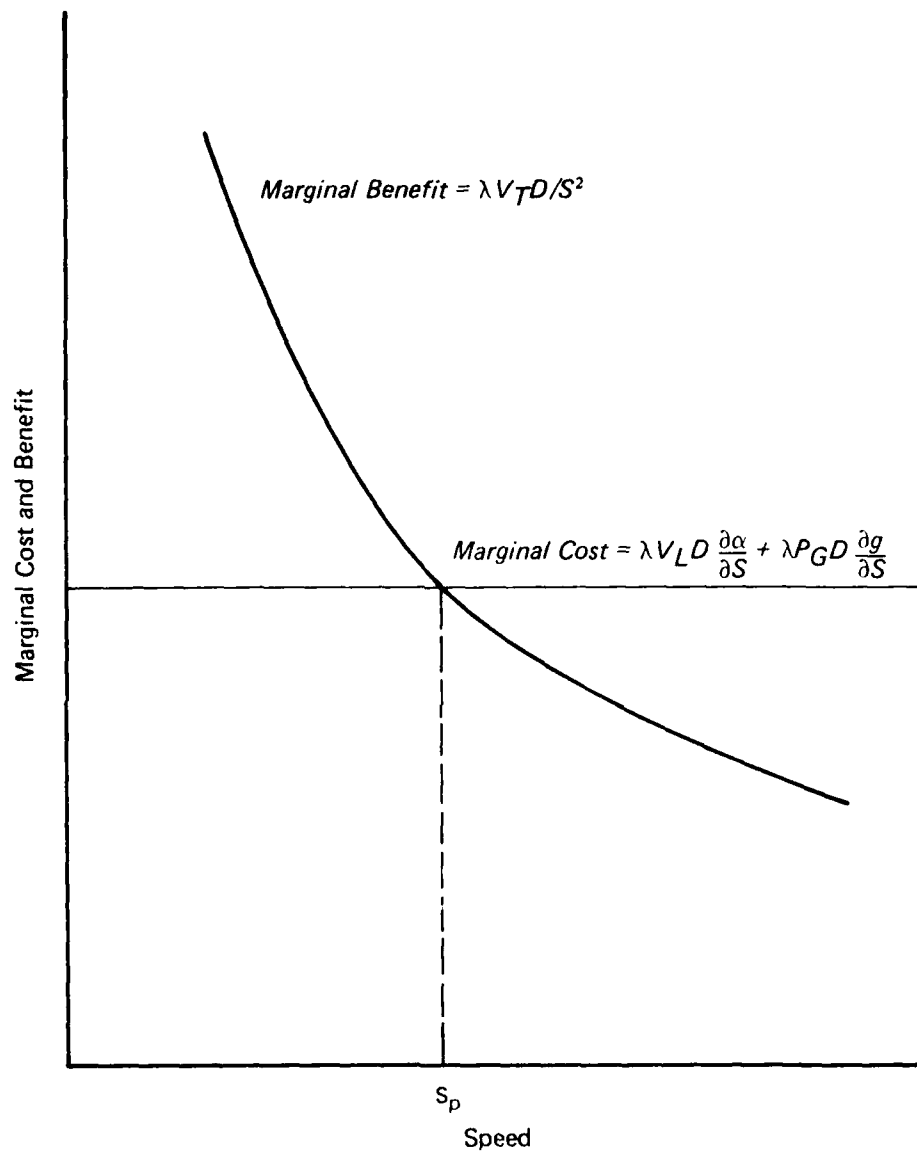


FIG. 1: THE OPTIMUM SPEED

a government imposed price ceiling on gasoline, which creates shortages and causes the private and social cost of gasoline to become unequal, the equation for S_p illustrates that the individual alone is fully capable of determining his optimal speed. If the government tries to interpose its own judgment of the private optimum, it can only guess at V_T , V_L , and the subjective probability of a fatality at higher speeds for individuals, and could only solve equation (1) for the "average" individual.¹

The Social Optimum

There does, however, seem to be one justification for government interference in this private decision, and it is one that is rarely mentioned, except perhaps by a small group of economists (see [4] and [6]). This is society's valuation of the increased probability of an accident at higher speeds that kills persons other than the speeders, i.e., the term $\partial\alpha/\partial S$.

A speeding driver not only increases the probability of killing himself but also of killing

¹It would, however, be able to determine P_G and $\partial g/\partial S$ from data collected from various government agencies.

others. Let us represent the increased probability of killing oneself by $\partial\alpha/\partial S$ and the increased probability of killing others by $\partial\alpha^*/\partial S$.¹ For simplicity, we assume a linear relationship so that social cost is given by $\partial\alpha/\partial S + \partial\alpha^*/\partial S$. The ratio of external to internal (or social to private) cost is thus given by $(\partial\alpha/\partial S + \partial\alpha^*/\partial S)/(\partial\alpha/\partial S)$ or $1 + \partial\alpha^*/\partial\alpha$. The term $\partial\alpha^*/\partial\alpha$, the externality ratio, will be represented by β and signifies the likelihood of another person being killed when a speeder is killed.

Assuming the costs of government intervention are outweighed by the benefits of reducing the externality, an optimal speed limit may be imposed with the proper information. The government should start from the personal optimum and adjust it only for externalities.

The determination of the socially optimal speed is given by equation (1), except for the additional term representing the externality, or

$$V_T/S_S^2 = V_L \left[\frac{\partial\alpha}{\partial S} + \frac{\partial\alpha^*}{\partial S} \right] + P_G \frac{\partial g}{\partial S} \quad (2)$$

¹In this analysis, we abstract from the fact that the probability of killing or being killed at a given speed is a function of the density of traffic on the road.

Solving this equation for S_S would yield an expression similar to that for S_P , except that an additional term would be involved. Unfortunately, the expression includes society's valuation of a life and of time, two values that are not easily obtained. To minimize information needs, we can, however, turn to equation (1) once again and solve for the ratio of the value of a life to the value of time, or

$$\frac{V_L}{V_T} = \frac{\frac{1}{S_P^2} - \frac{P_G}{V_T} \frac{\partial g}{\partial S}}{\frac{\partial \alpha}{\partial S}} \quad (3)$$

Rearranging equation (2) and substituting for V_L/V_T , yields

$$\frac{1}{S_S^2} = \frac{\frac{1}{S_P^2} - \frac{P_G}{V_T} \frac{\partial g}{\partial S}}{\frac{\partial \alpha}{\partial S}} \left[\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S} \right] + \frac{P_G}{V_T} \frac{\partial g}{\partial S}$$

Solving for S_S and using $\beta = \partial \alpha^* / \partial \alpha$ will yield the socially optimal speed limit which is related to S_P , or

$$S_S = \left[S_P^{-2} (1 + \beta) - \beta \frac{P_G}{V_T} \frac{\partial g}{\partial S} \right]^{-.5} \quad (4)$$

An important characteristic of equation (4) is that knowledge of V_L is not necessary. Knowledge of V_T is needed, but this is much less controversial. Further, it will turn out that the optimal speed limit (as calculated here but not elsewhere) is not sensitive to V_T .

APPLICATIONS

To see how (4) could be applied, consider a case in which $S_p = 85$ mph. This was roughly the actual, unrestricted speed on the Autobahn in Germany in 1975. The price of gasoline at this time was about \$1.50 per gallon. Using Castle [5], we get

$$\frac{\partial \alpha}{\partial S} (1+\beta) = 6.73 \times 10^{-10} \text{ deaths per vehicle mile/mph}^1$$

$$\frac{\partial g}{\partial S} = .0008706 \text{ gallons per mile/mph.}$$

We do not have data on the actual values for V_T , V_L , and β , but we can use (4) to calculate the optimum speed limit for various values of these parameters.

¹Because we only have information on the increased probability of a death for both drivers and nondrivers, the value for $\partial \alpha / \partial S$ will seem to depend upon β . This dependence describes our means of calculation, not any causal relation.

Since the private optimum is uniquely determined by V_T and V_L (given $\frac{\partial \alpha}{\partial S}$ and $\frac{\partial g}{\partial S}$), only one of these two parameters can be chosen independently if the unrestricted speed is to remain constant. In table 1, we have proceeded by assigning values to V_T and β and deriving the values for V_L and S_S that are consistent with a private optimum of 85 mph.

Several features of the results in table 1 are worth noting. First, the values for S_S are all less than 85, as expected. Second, for the range of β 's and V_T 's chosen, the optimum speed limit is above 70, which is well above the current limit of 55. Third, the value of S_S does not seem very sensitive to changes in V_T or V_L . For example, comparing the second and third cases in the table yields arc-elasticities of the speed limit with respect to V_L and V_T of .05 and .1 in absolute value. If instead the optimal speed limit were calculated directly from equation (1), the elasticities would be .25 and .5, five times as sensitive as our estimates. Thus, by restricting ourselves to combinations of V_T and V_L , consistent with observed speeds, the importance of these parameters is greatly diminished. Finally, the value of S_S is quite sensitive to changes in S_p .

TABLE 1

SENSITIVITY OF THE OPTIMAL SPEED LIMIT
TO VARIATIONS IN THE PARAMETERS

Unrestricted Limit = 85 MPH
Gasoline Price = \$1.5/gallon
(All figures in 1975 dollars)

<u>Value of Time</u>	<u>β</u>	<u>Value of Life</u>	<u>Optimum Speed Limit</u>
\$ 10	.5	174,256	83.8
15	.5	1,716,697	78.0
20	.5	3,259,137	75.6
100	.5	27,938,181	70.5
15	.25	1,430,581	81.3
15	.75	2,002,813	75.2

Unrestricted Limit = 75 MPH

<u>Value of Time</u>	<u>β</u>	<u>Value of Life</u>	<u>Optimum Speed Limit</u>
\$ 15	.5	3,032,912	67.0
15	.25	2,527,427	70.6
15	.75	3,538,398	63.8

If S_p were 75 mph, the value for S_s falls from 78 to 67 (for $V_T = \$15$, $\beta = .5$), an elasticity of about 1.25.

The Costs of a Suboptimal Speed Limit

The government imposed the national 55-mph speed limit ostensibly to conserve gasoline. With the recent decontrol of gasoline prices (and disregarding for now one possible externality we do mention in the next section), it would appear that gas purchases should remain a purely private decision. More recently, the 55-mile limit has been justified by its effect in saving lives. Assuming that it does, we might ask what is the cost per life saved by imposing the 55-mph speed limit when compared to the socially optimal speed limit obtained using equation (4). This means we must first calculate the total losses to society from its imposing a suboptimal speed limit of, say, 55 mph.

The consumer surplus loss from a suboptimal speed limit is derived by converting marginal cost and benefit from utility units to dollars and integrating between 55 mph and the socially optimal limit. For the calculation, we use an example from table 1 where $S_p = 85$ mph, $V_T = \$15/\text{hr}$, $\beta = .5$ and $P_G = \$1.5$ per gallon. According to table 1, $S_s = 78$ mph and the implied value of a life is equal to \$1,716,697.

Figure 2 illustrates graphically the calculation we wish to make. The private optimum was obtained as in figure 1 by equating MB and MC (private). The social optimum is obtained when MC (social) is equated to MB. The difference between MC (social) and MC (private) is equal to $\lambda V_L D \frac{\partial \alpha^*}{\partial S}$. This is the valuation of the externality caused by increased speed, i.e., the value of lives lost by people other than the offending driver when he goes faster. We stated that MC(social) = MB at a speed of 78 mph. Imposing a speed limit of 55 mph when it should be 78 causes a loss in consumer surplus equal to the shaded area in figure 2.

This loss may be found by calculating the following integral:

$$CS = D \int_{55}^{78} \left[V_T \frac{1}{S^2} - V_L \left(\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S} \right) - P_G \frac{\partial q}{\partial S} \right] dS$$

Using the values for V_T , V_L , β , $\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S}$, and $\frac{\partial q}{\partial S}$ given earlier and $D = 1025$ billion miles (the average traveled per year in the U.S. in the last few years, from [10]), we obtain a loss from a nonoptimum speed limit of approximately \$24.4 billion per year.

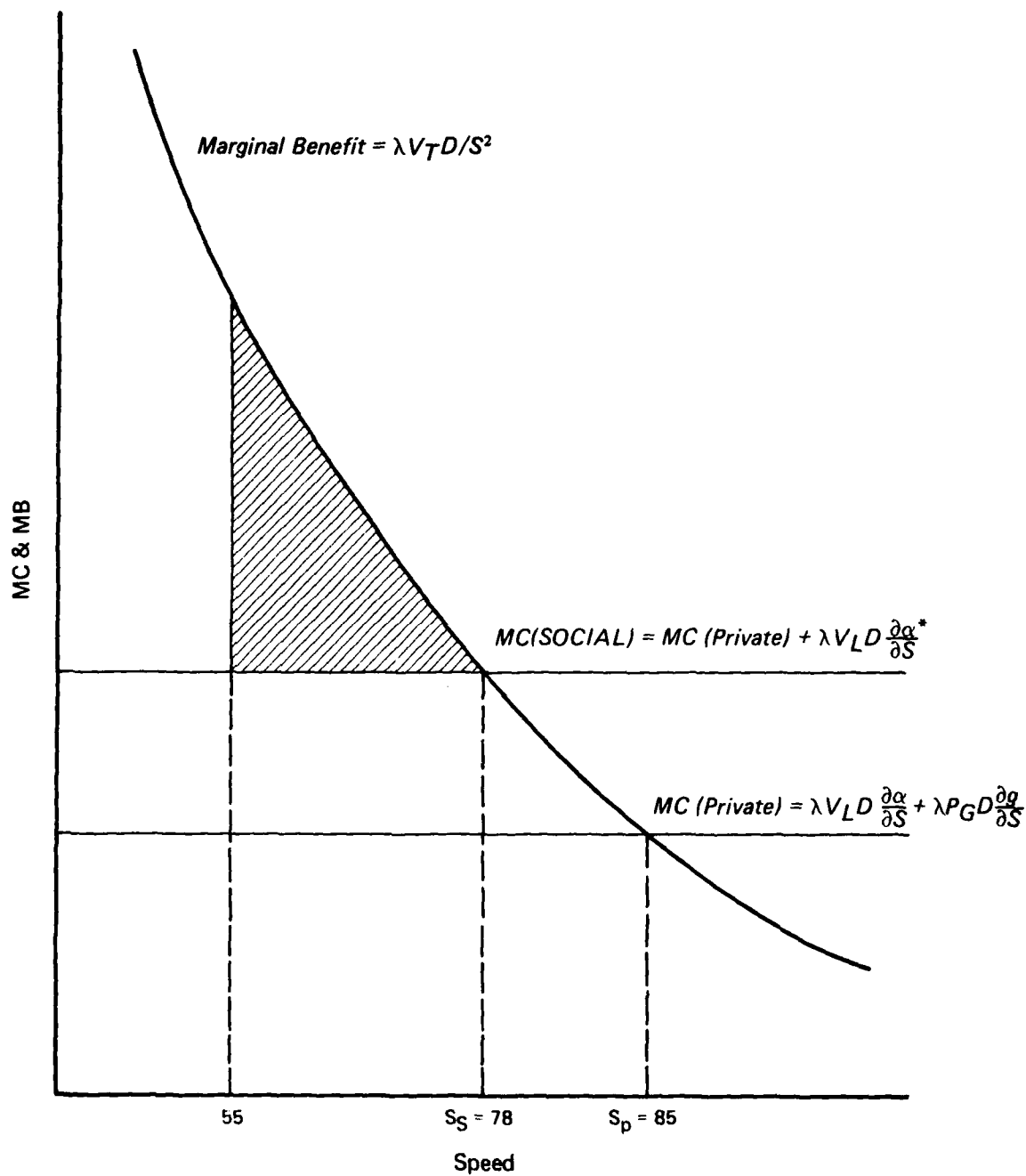


FIG. 2: THE COSTS OF THE SUBOPTIMAL SPEED LIMIT

The reduction in the probability of being killed by reducing the speed limit from 78 to 55 mph is equal to 1.55×10^{-8} per mile $((\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S}) \times (78-55))$. This implies about 15,888 lives are saved per year by having a 55-mph rather than a 78-mph speed limit. The cost is therefore about \$1.5 million per life over and above the value individuals place on their own lives or a total of about \$3.2 million. How does this compare with the cost of other ways of saving lives? A survey of the cost of saving lives in 57 cases of federal safety efforts [9] reveals only 12 more expensive.

FURTHER RESEARCH

What we have presented is a highly simplified model without precise parameter estimates. What is needed is the construction of a more sophisticated model with the same emphases--the focus on externalities and the ability to use the vast amount of information embodied in observed speeds.

Extensions of the research in this paper would include a consideration of other externalities, for example, a rapid driver forcing a slower driver to speed up in self defense. They would also include a consideration of nonfatal accidents.

The 55-mph speed limit was meant to save fuel. From an externality point of view, this does not make sense. Purchasers take account of the full cost of the fuel. There is, however, an externality argument. If the speed limit reduces the import price of gasoline, then consumers in the U.S. receive a gain without a corresponding loss to someone else in the U.S. The amount of the gain can be shown to be equal to

$$\text{gain} = -(pm)(\%dp)$$

where pm is expenditures on imported oil (for gasoline)

$\%dp$ is the percentage change in the price of oil.

Finally, it is obvious from our numerical calculations that much needs to be done in the way of parameter estimation. Externalities are at the heart of the optimal speed limit, yet the Federal Government's research programs are not at all directed toward discovering the degree of externality. Acceptance of our methodology would imply a major redirection of research.

CONCLUSION

We have worked through an example of a methodology for determining the optimal speed limit.

The conclusions can be summarized as follows:

- (1) To determine the optimal speed limit, two parameters are of crucial importance: (a) the uncontrolled speed, (b) the ratio of external costs to internal costs. Data collection efforts should be focused here.
- (2) If our crude calculations are at all indicative, the optimal speed limit is well above 55 and the speed limit is an expensive way to save lives. There are better opportunities for life saving elsewhere.
- (3) The value of life does not directly enter the calculation of the optimal speed limit. The value of time enters with less importance than in usual calculations. In general, the information needed for the calculation is changed as well as the relative importance of different pieces of information.
- (4) We suggest a major redirection of highway research to discover the extent of externalities.

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